

Power Parks System Simulation

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Abstract

The objective is to develop a system model to simulate distributed power generation in power parks, where power generation is co-located with businesses or industries. The deliverable of the project will be a tool for simulation of the local power generation system, constructed in the Simulink software. We have developed a library of modules for the various components being proposed for power parks. We assembled the components into a sample power park, in which a reformer operates at a steady rate to produce hydrogen, feeding a fuel cell stack to supply electricity to a transient load.

Introduction

Power parks are distributed energy sites where power generation is co-located with businesses or industrial energy consumers. Proposed power parks use combinations of technologies. A local power source is often combined with a storage technology to adapt the dynamic of the source to the load. In some cases, the system operates completely separate from the utility grid. Alternatively, the power park may use the utility grid as a storage device, selling power to the utility when there is excess and drawing power when the local source cannot meet the load.

Often, power parks are sited in order to take advantage of a renewable energy source. Generation by photovoltaic collectors or wind turbines can be combined with energy storage technologies. Power parks provide an excellent opportunity for using hydrogen technologies. Electricity from the renewable source can be used to generate hydrogen by electrolysis and stored for use in fuel cells or to refuel vehicles. Similarly, heat from a renewable source can be used to reform hydrocarbon-fuels into hydrogen.

The variety of technologies and their combinations that are being proposed for power parks suggests that each system will be novel, at least in some aspect of its design.

Consequently, a simulation tool will be very useful in evaluating the systems, and optimizing their performance with respect to efficiency and cost.

Approach

The deliverable of the project will be a tool for simulation of the local power generation system, constructed in the language of the Simulink software [1]. Simulink provides a graphical workspace for block diagram construction. The workspace provides the flexibility to quickly assemble components into a system. Simulink performs dynamic simulation by integrating the system in time using a collection of ordinary differential equation solvers. After the simulation is completed, the solution can be examined by plotting variables at various states in the system. Simulink also contains modules for dynamic control and solution of iterative loops within the system.

The software design begins with development of a library of Simulink modules that represent components in the power system. The component models are based on fundamental physics to the extent practical. These models are generic, in that they are not customized to represent a specific brand or manufacturer's features for the component. However, the generic components from the library can be tied to a specific unit by relying on performance data. The library components can be quickly modified to represent new or specialized components, thereby expanding the library's collection.

Many of the basic modules that represent hydrogen and other gas mixtures use the Chemkin [2] software package to provide thermodynamic properties of the species and mixtures. For example, the Mixer component accepts two gas streams and adiabatically mixes them to yield an output stream. The temperature of the new stream depends on the temperatures, compositions, and relative flow rates of the two inlet streams. Solution for the outlet temperature uses Newton iteration over Chemkin calls, which return the updated enthalpy of the mixture. Another example is the Equil module, which computes the equilibrium composition at a given temperature and pressure. This module is coupled to a Chemkin-implementation of the Stanjan [3] equilibrium solver. The Equil module is used to represent chemical reactions in either a reformer or a combustor component.

Results

We have developed a library of Simulink modules for some of the various components being proposed for power parks. Existing components include a fuel cell stack, a steam-methane reformer, a multi-stage compressor, a high-pressure storage vessel, and an internal electric load. The load versus time is read from a file, so it can be changed quickly.

The steam-methane reformer (SMR) takes an input flow rate of methane and computes the hydrogen output. Hydrogen separation is achieved by a membrane, which is modeled by retaining a specified partial pressure of hydrogen in the reformat stream. The SMR module balances energy by combusting the reformat stream with air and exchanging the heat released to the catalyst reactor. Both the combustor and reactor sub-modules use chemical equilibrium to represent the output composition. Parameters on the SMR are the steam-to-carbon ratio and the outlet temperature of the exhaust products from the internal burner. The temperature at which the equilibrium reforming occurs depends on these parameters. Figure 1 shows the variation in thermal efficiency of the SMR with temperature and steam-to-carbon ratio. The minimum steam-to-carbon ratio is 2; however, reformers are often operated with excess steam to improve the efficiency and prevent coking problems. More detailed analysis of the SMR sub-system is presented in reference [4].

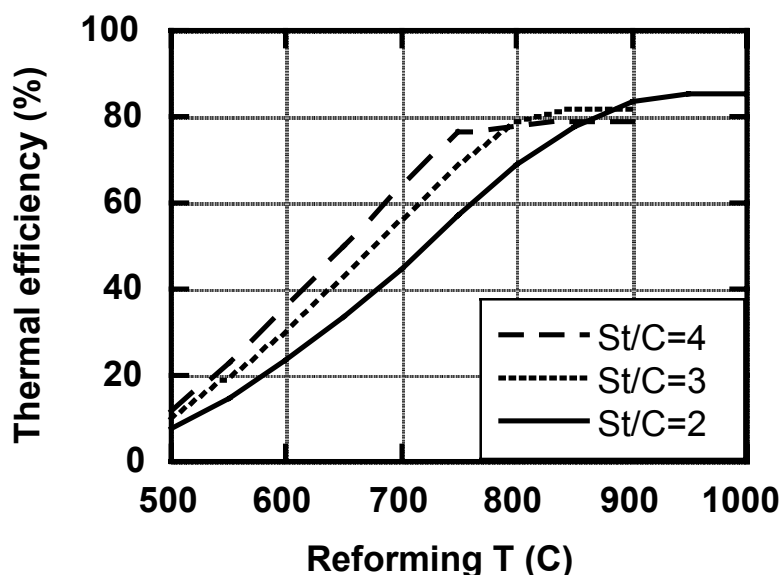


Figure 1. Thermal efficiency of the steam-methane reformer module versus the temperature and steam-to-carbon ratio.

The fuel cell module takes a hydrogen inlet flow rate and a requested power, then determines if sufficient power can be supplied. The stack model uses a simple map of efficiency versus power. This data is read from an input file to allow the fuel cell to be calibrated to real performance data. If sufficient power can be provided, the excess hydrogen flow is returned for compression and storage. A compressor module represents an ideal two-stage compressor that assumes isentropic compression in each stage. The power required by the compressor is included in the analysis of the overall thermal efficiency of the system.

The block diagram for the sample power park is shown in Figure 2. A steam-methane reformer operates at a steady rate to produce hydrogen. The hydrogen feeds a fuel cell stack to supply electricity to a transient load. When the power requested from the stack is supplied sufficiently, excess hydrogen is compressed and stored. The simulation in this example runs over a daily load cycle.

The power output by the fuel cell, which in this case matches the demand, is shown by the solid line in Figure 3. The power consumed by the hydrogen compressor is shown by the dotted line in Figure 3. During the night, when the load is low, the compressor load is large because most of the hydrogen produced by the reformer is being compressed for storage. During the peak daytime loads, the compressor is not operating, because there is no excess hydrogen.

The model evaluates the overall thermal efficiency of the power system, as shown in Figure 4. The system efficiency is the hydrogen stored and electric power supplied to the load, divided by the methane input to the reformer and the power consumed by the compressor. The system efficiency is highest when the reformer is producing hydrogen to be stored. In contrast, the system efficiency drops when the combined reformer and fuel cell are working at capacity to supply the peak load.

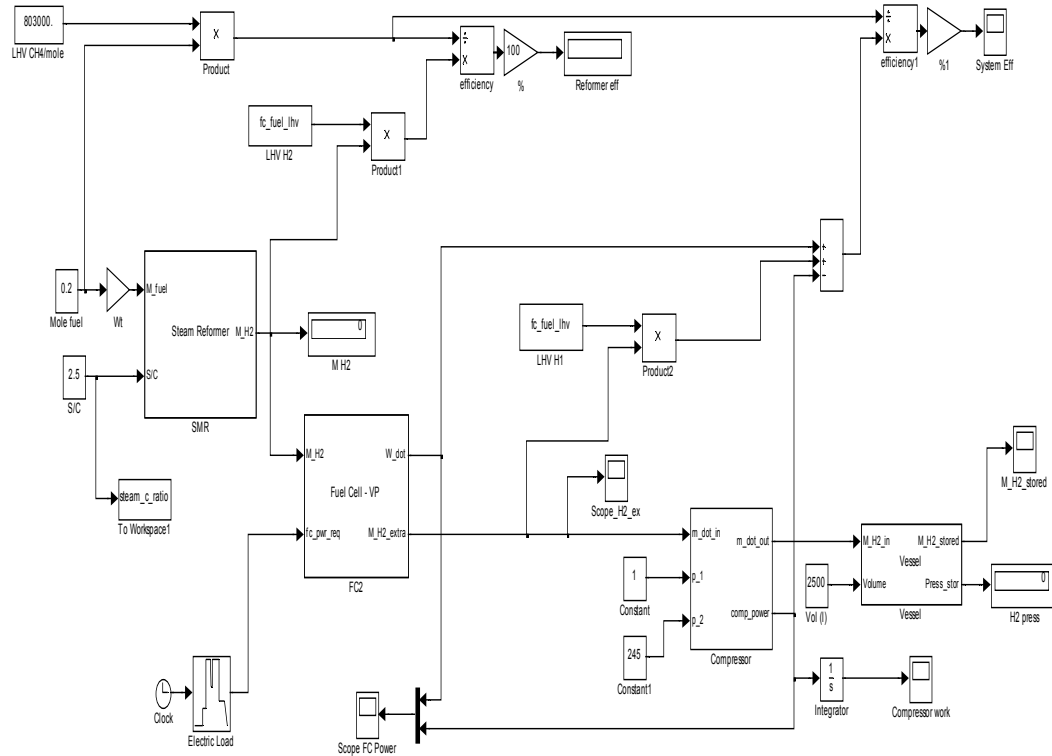


Figure 2. Block diagram (from Simulink workspace) for sample power system. Simulation results for power and thermal efficiency over the daily cycle are shown in Figures 3 and 4.

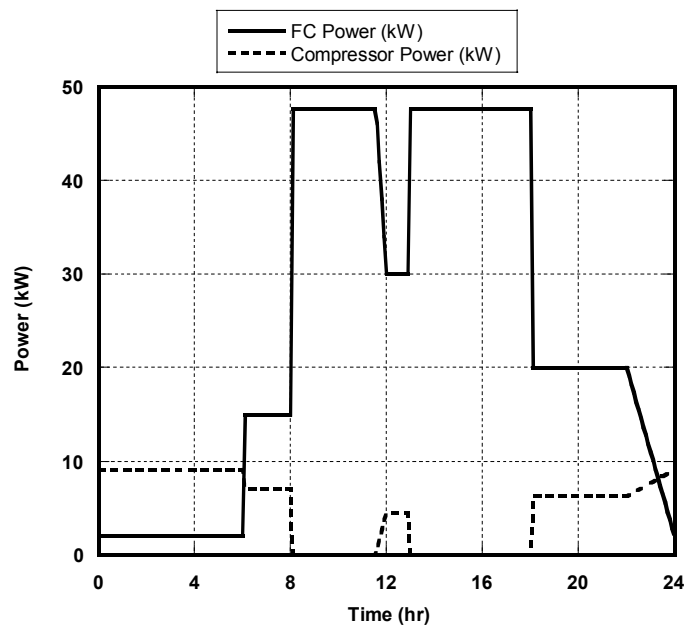


Figure 3. Power output of the fuel cell (solid line) and power consumed by the compressor (dashed line) for a sample simulation over a daily cycle.

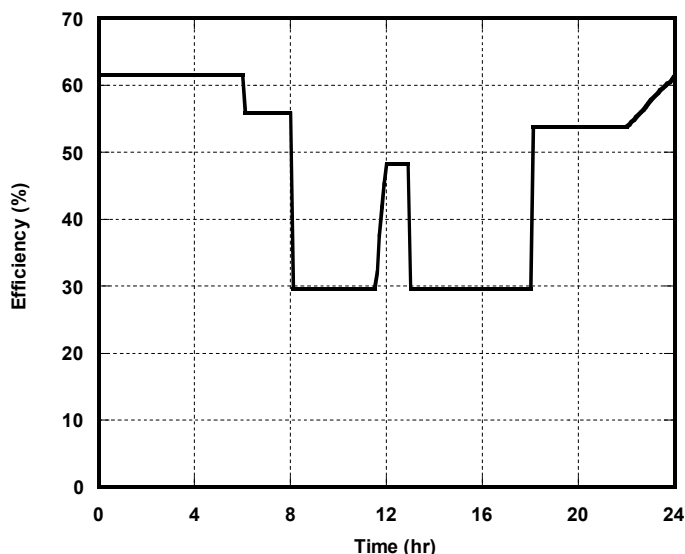


Figure 4. Thermal efficiency of the power system for a sample simulation over a daily cycle.

Future Work

As we consider a variety of power park designs, we will continue to develop modules for the Simulink library. We expect to add modules for electricity generation by a PV array and hydrogen generation by an electrolyzer and other reformer types, such as partial oxidation or autothermal reformers.

The final stages of the work will implement a control strategy to direct the power within the park to balance meeting internal load with external power supply. We will also include a layer of analysis to compute the cost of the power and hydrogen generated. The cost analysis will accept input of the initial capital costs of the components, as well as the continuous operation costs during the life of the simulation, and add the costs using time-value adjustments. We expect the simulation tool will provide valuable assistance in the planning and design of hydrogen technologies in distributed power systems. In addition, the simulations of dynamic performance can be compared with data collected from demonstration sites.

References

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